Wildfire Factors Affecting Grid Resilience in PG&E Electrical Distribution

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ABSTRACT

Wildfire prone weather conditions have become more extreme and common across the West Coast, including California. Simultaneously, the electrical grid across the state is ever expanding and essential to power our lives. These two factors combined can be a recipe for disaster as seen in the Paradise Fire in 2018, where a degrading PG&E power line sparked a deadly wildfire. The result of this led to the creation of Public Safety Power Shutoffs (PSPS) where the utility turns off power during inclement weather. This means that some communities are forced to live without electricity. To understand this problem, I compiled a variety of datasets from the California Public Utilities Commission, the California Energy Commission, PSE Healthy Energy, Landfire, Pyrologix and CalEnviroscreen 4.0 to create spatial maps on ArcGIS Pro and a correlation matrix on Python. I found that tree cover is highly positively correlated (93-72%) with outage impacts, more so than wind speeds (50-46%). Additionally, at risk transmission line miles are correlated with increased outage frequency (63%). However, there are no stark correlations with outage duration. This means that a focus on vegetation management remains critical to reducing the risk of outage as wildfire prone conditions are heavily dependent on tree cover surrounding the power line. As well, the lack of factor correlating to outage duration indicated that microgrids are a good option to mitigating the effects of outage on communities.

KEYWORDS

Electrical Grid, Power Outage, Public Safety Power Shut Off, Vegetation Management, Microgrid, Burn Risk

INTRODUCTION

Clean energy is becoming increasingly significant, in the process of decarbonizing and combating climate change, leading to a surge in investments in electrical systems, as clean energy sources are predominantly usable through electricity (Gielen 2019; Deason et al 2018; Pacala and Socolow 2004). As well, previously implemented policies have prompted a heavy push into electrification to meet carbon emission reduction goals (Gielen 2019). Thus, reliance and investment into the electricity grid is becoming a bigger aspect of American life, especially in California. Now, more than ever, we require electricity to charge our devices, power our cars, cook our food, and climate control our homes; and this demand is only predicted to grow. This increased reliance on electricity has increased outage and fire risk from an already aging system throughout Northern California (Blunt 2022). Development out of over-populated urban hubs in Northern California has also grown, placing many more people along the urban-wildland interface, an area at high wildfire risk (Kramer et al. 2019). This means that new power lines are being built in high hazard zones and old ones are creating new hazard zones. The combination of increased electric demand, an aging system, and the rising risks from climate-induced wildfires present a precarious situation for this region.

Increased wildfires in Northern California pose great risks to the electrical system and have generated the need for new grid management practices. Shifting weather patterns, along with historically poor landscape management practices, have led to a variety of devastating, deadly wildfires in the region (Prein 2022; Guiterrez et al. 2021). In general, natural disasters and extreme weather events pose a large risk to the electricity grid and are the biggest reason for blackouts in the United States (Mukherjee et al. 2018). In Northern California, wildfire-induced blackouts are having a considerable effect on the electrical supply, a problem that only increases as wildfires become more frequent (Dale 2018). There are three reasons for wildfire related blackouts: most commonly, the utility will implement public safety power shut-offs (PSPS) to prevent wildfire ignitions under high fire risk weather scenarios (Blunt 2022). Secondly, the wildfire may cause damage to the electricity grid infrastructure leading to inevitable and long term blackouts. Thirdly, PSPS are used to prevent damage to power lines from high heat, wind, or vegetation (Sayarshad and Ghorbanloo 2023). Considering the simultaneous increased reliance on electric power for communication and transportation, these blackouts could lead to real disaster. Work is being undertaken to reduce the risks and effects of powerline-induced wildfires without constant blackouts.

A few methods have been undertaken by PG&E to mitigate the future risk of wildfires caused by power lines and reduce PSPS. Firstly is vegetation management where crews will clear vegetation away from existing lines to reduce fuel load and mitigate the risk of power lines touching flammable material during risky weather (PG&E). The second is undergrounding. In this approach, overhead power cables are replaced by underground cables. This prevents any exposure of the power lines to variables that cause wildfire and significantly reduces the impact of wildfire on power lines (PG&E). Undergrounding can be very costly and time inefficient. However, it is ideal for power lines that support large communities as the investment likely pays off quicker and it is the most reliable way of providing power during high wildfire weather conditions (Perera et al. 2023; Blunt 2022). Lastly, microgrids and remote grids can be used to provide power in the case of blackout. Using this method, communities can be disconnected from the larger electric grid as necessary so that they maintain consistent power regardless of wildfire hazard or other risks to transmission lines (PG&E). Microgrids or remote grids are newer strategies,so there are complications and less expertise in establishing a working system that integrates with our pre-existing electrical grid. However, they are a good way of providing power to smaller, remote communities where undergrounding power lines is not a financially feasible option (Perera et al. 2023; Yang et al 2023). On April 6, 2023 the CPUC established funds for a new program called the Microgrid Incentive Program which provided funding for microgrid installations to select communities across the state. The program is being implemented through the three California utilities (PG&E, SCE, SDG&E) (CPUC). To be eligible for PG&E's Microgrid Incentive Program, communities must be considered either "vulnerable to outages" or "disadvantaged and vulnerable" (PG&E 2023). Vulnerable to outage communities are any community in a tier 2 or 3 fire district, has experienced prior outages, or with lower historical reliability. Disadvantaged communities are communities with low median income, tribal communities, high risk per CalEnviroscreen or a rural area (PG&E 2023). Effective methods to provide power to people in the face of consistent wildfires exist, but knowing where to implement them poses a new set of challenges.

To fill this gap, my thesis aims to answer how wildfire risks in California affect access to clean, reliable energy in these regions. In the literature, there is a lack of knowledge on how robust large scale electrical grids are in the face of wildfire, as well as where and who are most affected by the risks. I would like to explore further which transmission lines and distribution regions are most affected by wildfire: Is there overlap between communities in high wildfire risk zones and those with high risk transmission lines? Are these communities most affected by outages? After addressing this, I want to examine if there is a relationship between community demographics and who is affected. Lastly, I would like to assess which communities are ideal for remote grids based on outage risk and economic feasibility. I predict that remote communities, especially those with geographic barriers, will be most affected by PSPS and that microgrid solutions will be more effective than large scale undergrounding projects. I am going to use publicly available data from a variety of sources including Pyrologix, the California Energy Commission, and the US Census for my preliminary analysis.

METHODS

Study site

My study site is located in California, generally Northern California, and includes any census blocks (based on geoid) that are powered via PG&E electrical lines that experienced a PSPS event in the past five years.

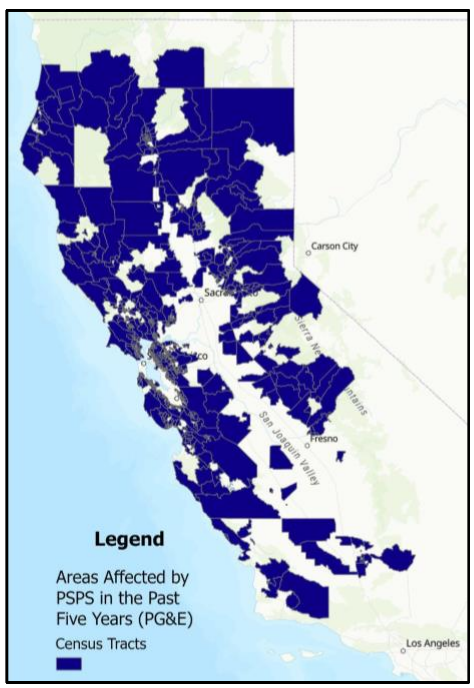

Figure 1. Assessed Area. Census tracts affected by PSPS in the past five years.

Data collection

In order to answer my research questions, I worked with a variety of agencies to collect and access relevant data. I collected data in four categories: wildfire risk, PG&E electrical grid, historical outages, and community demographics. Some of this data was specific to selected study sites, while others were first processed to select for the study site's census blocks' later in the analysis process.

Wildfire risk

Firstly, I started by gathering information to assess the fire threat in the region. Through LANDFIRE, a landscape scale geo-spatial product that was created and shared by the U.S. Department of Agriculture Forest Service and the U.S. Department of the Interior's wildland fire management programs, I was able to download point data on the canopy cover across California (Landfire, 2022). The California Public Utilities Commission (CPUC) provided a fire threat map that identifies middle and high threat fire risk zones throughout California (California Public Utilities Commission, 2024). These threat zones are areas where, due to a variety of factors such as fuel load and weather, the utility is at a higher risk of sparking an ignition. I was also directed to another more holistic fire model through Pyrologix, a wildfire threat assessment research firm, which provided me with wildfire hazard, burn probability, and extreme fire risk data that took into account topography, fuel load, and weather conditions in the region (Pyrologix, 2023). The firm also broke down some of the factors they used in their wildfire risk assessment, and so I was able to source my wind speed data from here as well.

PG&E electrical grid

The second category of data collection pertained to gathering spatial information on the California electrical grid. Through the California Energy Commission (CEC), I was able to find a map of all the transmission lines throughout the state which I used to understand which utilities powered which regions and how interconnected each census block was (CEC 2024).

Historical outages

The third data category was collected under which census blocks were affected by outages. PSE Healthy Energy, an independent scientific research institute, shared a dataset of past PSPS events across the state by census block, which I used to understand which communities have been affected by outages (PSE Healthy Energy 2023). A variety of attributes were included in this dataset including average outage frequency, average outage duration, and average number of customers impacted for each affected census block.

Census demographics

Lastly, I collected demographic data on my affected populations. This was done through US Census data and a public dataset available through the environmental justice tool, CalEnviroscreen 4.0. From the US census data I selected median income, population, and unemployment rate in each census block. From the CalEnviroscreen dataset I selected for the following categories in each census block: disadvantaged communities (yes/no), CalEnviroscreen score (accounts for pollution burden and population characteristics), population characteristic score (general score to account for socioeconomic factors), education, poverty, unemployment, pollution levels, linguistic isolation, and housing burden (OEHHA 2024). I chose these factors because they best represent and set apart different communities.

Data analysis

Assessing at-risk geographic regions on ArcGIS Pro

First, I found which transmission lines were at risk. Starting with the CPUC fire threat map, I identified the wildfire risk zones. High wildfire risk areas were those labeled as level 2 or level 3 on the map. I uploaded the map as a KML file which I converted to a polygon layer. After this, I used the “Clip” tool to assess which stretches of transmission lines from the CEC transmission line map were at high risk. I then split all these lines along census block borders using the “Spatial Join” and “Identity” tools to find the isolated segments of each line in a census block. Lastly, I found the total mileage of the at risk transmission lines in each census block using the "Calculate Geometry Attributes" tool.

To find the spatial distribution of wildfire risk factors across the state I Used the shapefiles from Pyrologix which imported point data about the characteristic wind speeds, burn probability, probability of extreme fire, and wildfire hazard potential into my workspace. Then I used the "Zonal Statistics" feature to find the average or maximum of each feature by census block. Using this I mapped the above wildfire factors by census block across California. Then, I imported a point data canopy cover file from LANDFIRE. Similarly, I used the "Zonal Statistics" feature to find the average tree cover in each census block, and mapped accordingly.

The last feature was the outage data. Using the CSV file from PSE Healthy Energy that recorded outage data by census tract I selected for PG&E outages only and then ran a "Join" command with a census tract shapefile so that I could easily map the outage duration, outage frequency, and customers impacted in each census block. I then exported the CSV file to Python, ran some simple calculations to create an "impact" metric (Outage Duration * Outage Frequency), and two people-based metrics (impact/customers or impact/census block population). This new CSV was then imported back into ArcGIS Pro and similarly ran a "Join" command with a census tract shapefile so that I could map the impact and effect of outages on people by census tract.

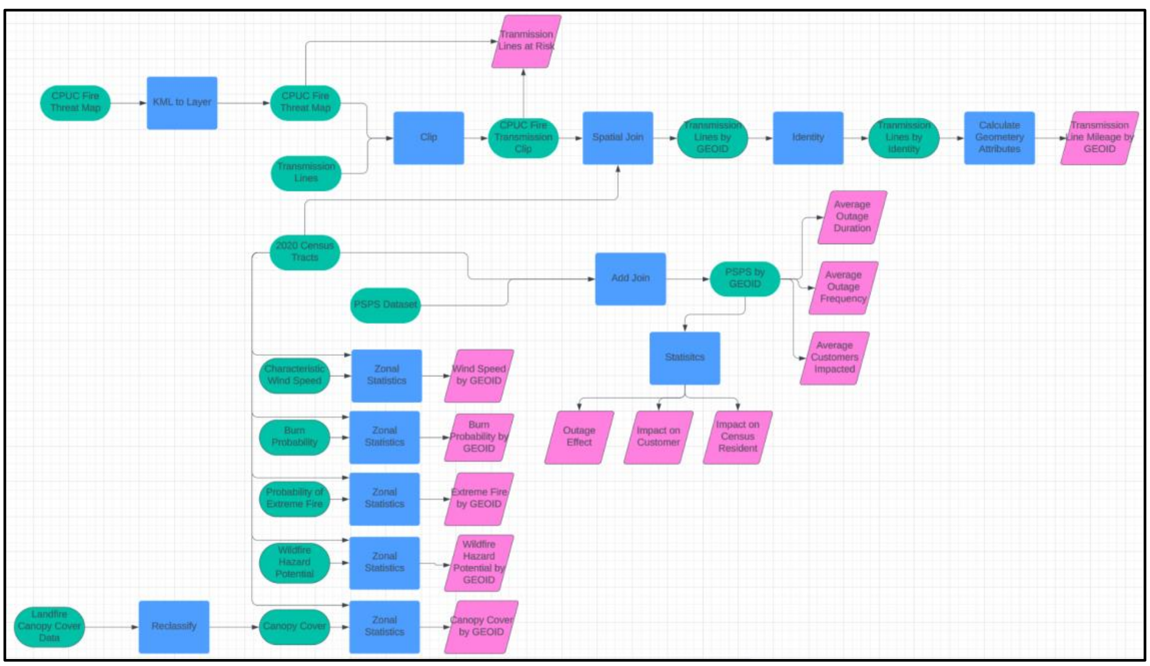

Figure 2. ArcGIS Pro Process to Create all 13 Maps

Assessing correlations for PSPS on python

Once I had finished my analysis on ArcGIS Pro, I moved to Python to test for correlations between outage impacts and demographic and wildfire data. I exported data tables of all the factors I had mapped by census tract (wind speed, burn probability, extreme fire probability, wildfire hazard, canopy cover, at-risk transmission line miles, outage duration, outage frequency, average customers impacted, outage effects, impact on customers, and impact on residents) into Python. I then cleaned all the datasets and combined them into one large dataset. It had values for each census tract powered by PG&E that had experienced a blackout. This dataset was then joined with a dataset from CalEnviroscreen to add demographic data. Once this final dataset was created I ran a Pearson correlational analysis to create a correlation matrix mapping out the relationship between all variables in the dataset to each other.

Assessing microgrid/ battery potential

Finally, in order to determine the possibility and feasibility of microgrid/battery installations to mitigate the effects of PSPS, I identified communities that would qualify for PG&E's microgrid incentive program. Since every community in my dataset qualified for the historical blackout criteria I first filtered my dataset to select for disadvantaged communities. The second time the dataset was filtered for communities with high wildfire risk. Here I looked at any community that crossed the threshold for high "Wildfire Hazard Potential."

RESULTS

PSPS mapping

The following maps are the results of the ArcGIS Pro Analysis.

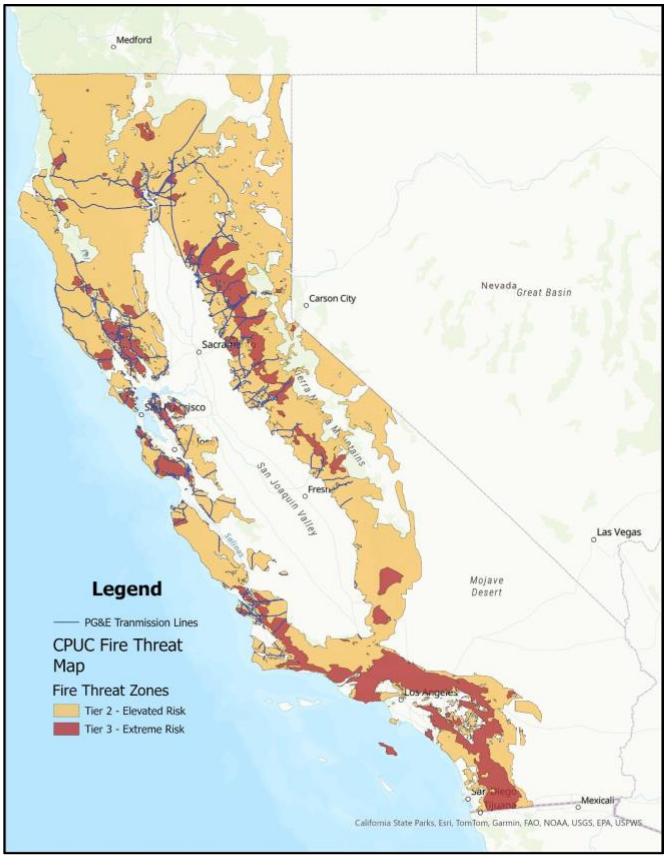

Figure 3. CPUC Fire Threat Map with At-Risk PG&E Transmission Lines

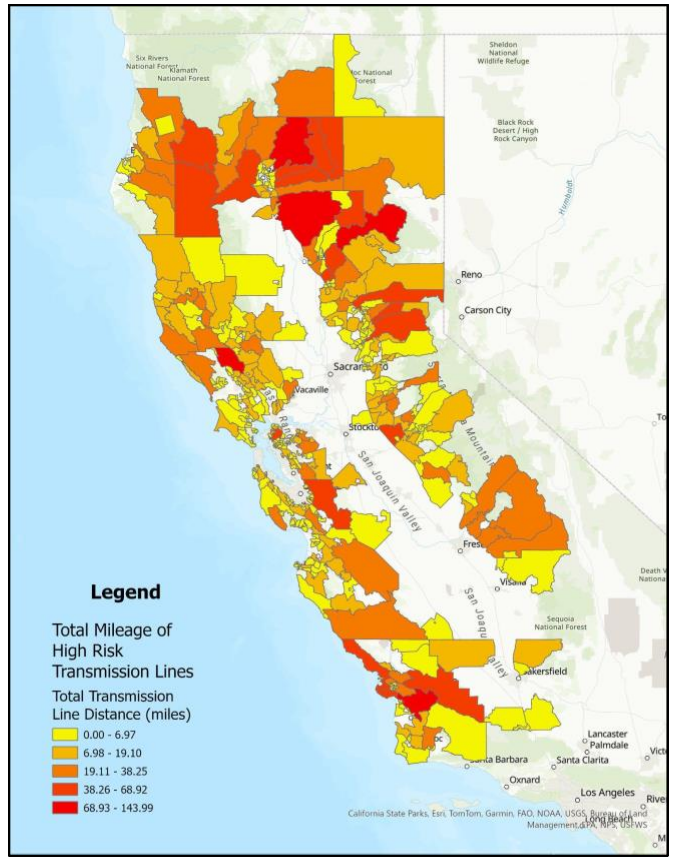

Figure 4. Total Mileage of High Risk Transmission Lines

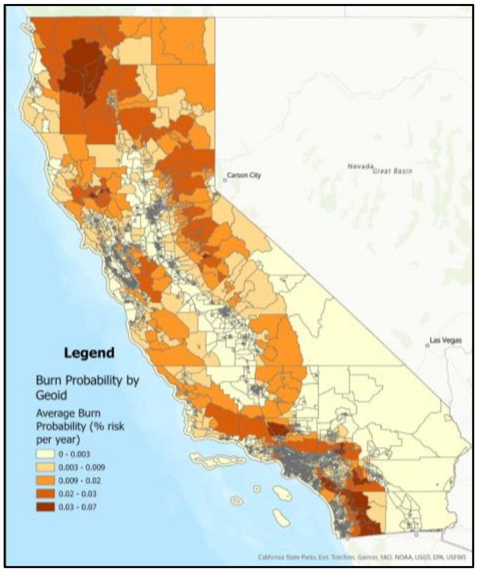

Figure 5. Burn Probability by Census Block

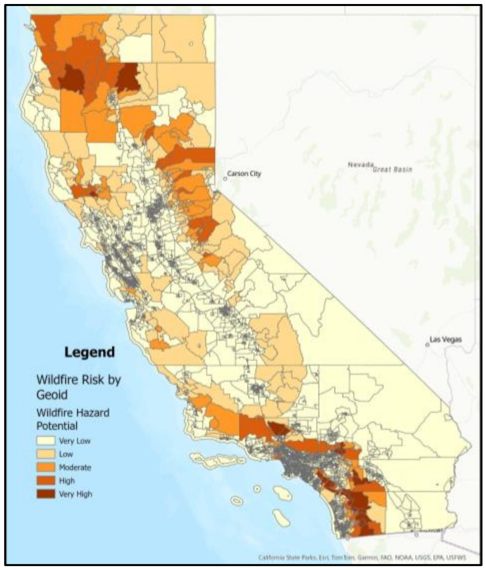

Figure 6. Wildfire Hazard Potential by Census Block

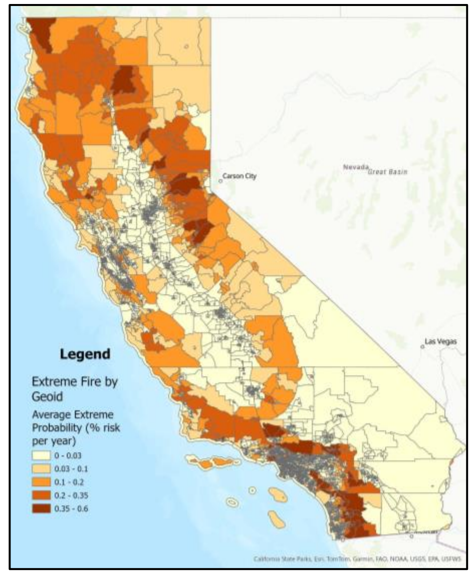

Figure 7. Extreme Fire Probability by Census Block

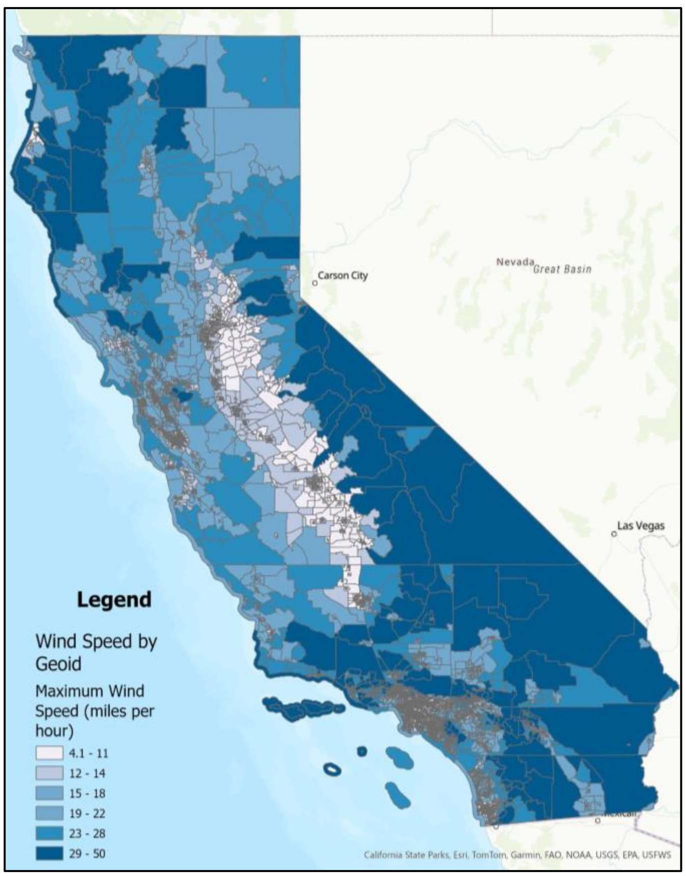

Figure 8. Max Wind Speed by Census Block

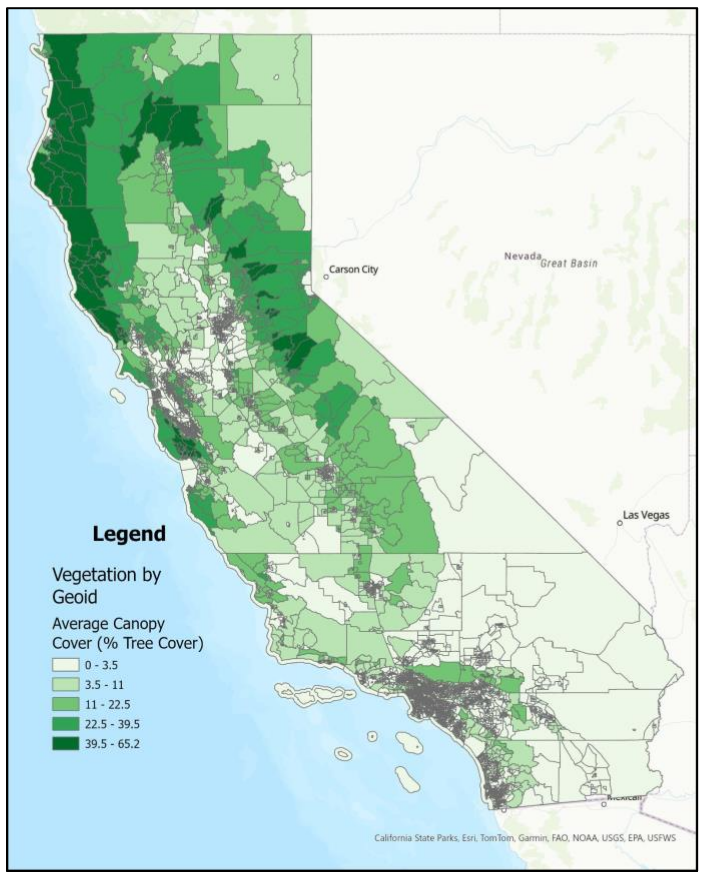

Figure 9. Average Canopy Cover by Census Block

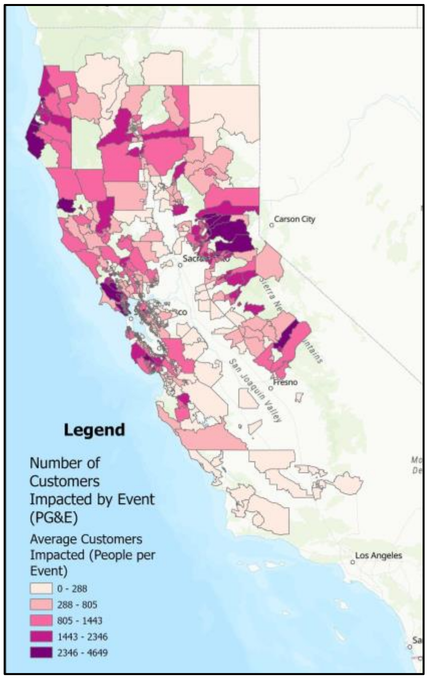

Figure 10. Number of PG&E Customers Impacted by each Outage

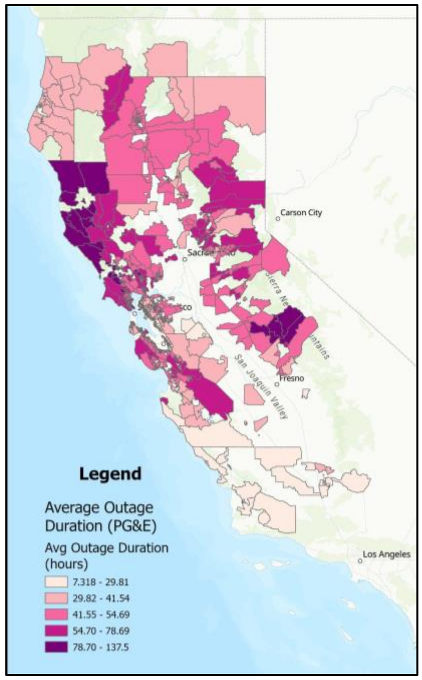

Figure 11. Average Outage Duration for Census Blocks with PSPS Events

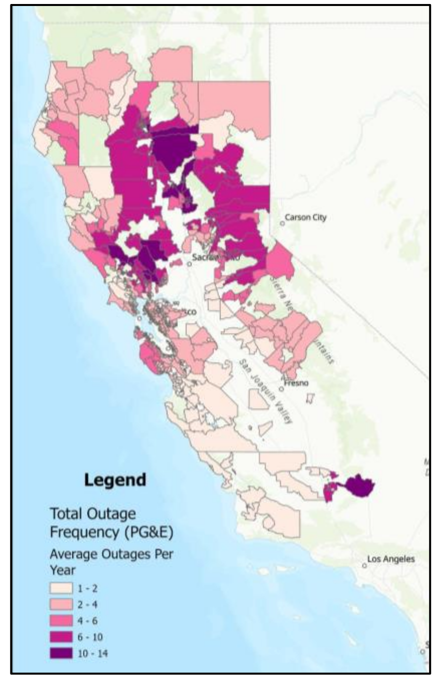

Figure 12. Average Outage Frequency for Census Blocks with PSPS Events

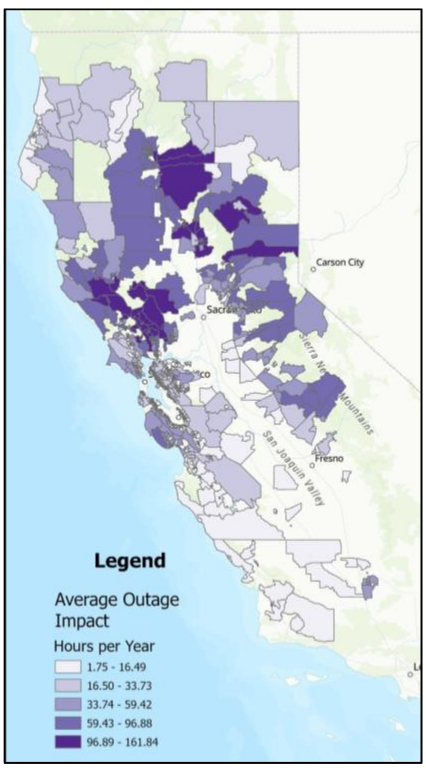

Figure 13. Average Outage Impact for Census Blocks with PSPS Events

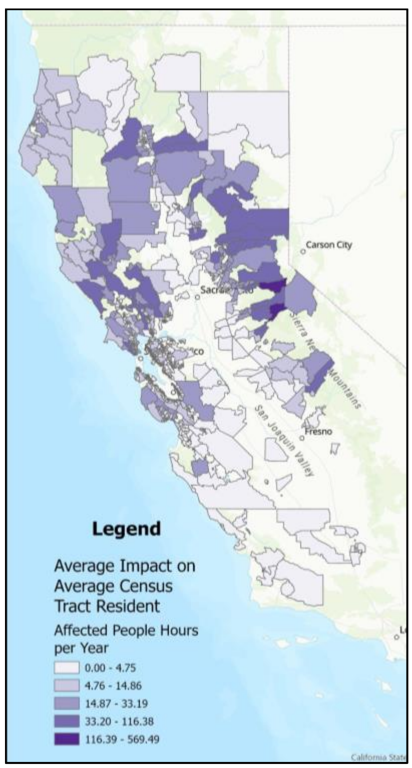

Figure 14. Average Outage Impact for Residents Census Blocks with PSPS Events

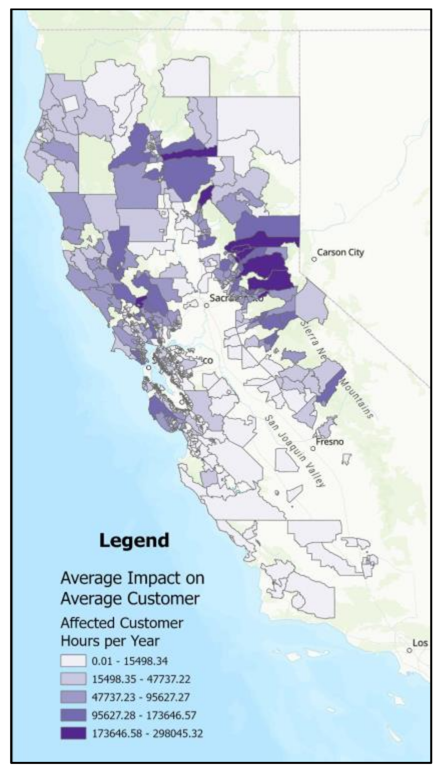

Figure 15. Average Outage Impact for PG&E Customers Census Blocks with PSPS Events

The regions most impacted by PSPS are: Humboldt County, Mendocino County, Placer County, Nevada County, El Dorado County, and Marin County (Figures 2-7). The regions with high transmission line risk are: Shasta County (06089012606), Tehama County (06103000100), Plumas County (06063000400), Sonoma County (06097154100), Butte County (06007002401) (Figure 8).

Wildfire and demographic effects on PSPS

I found a couple demographic and environmental factors related to higher PSPS rates (Figure 16). Tree cover is highly positively correlated (93-72%) with outage impacts, more so than wind speeds (50-46%). Population density and linguistic isolation are highly negatively correlated with outage impacts (-74%, -78%). At-risk transmission line miles are correlated with increased outage frequency (63%). However, there are no stark correlations with outage duration.

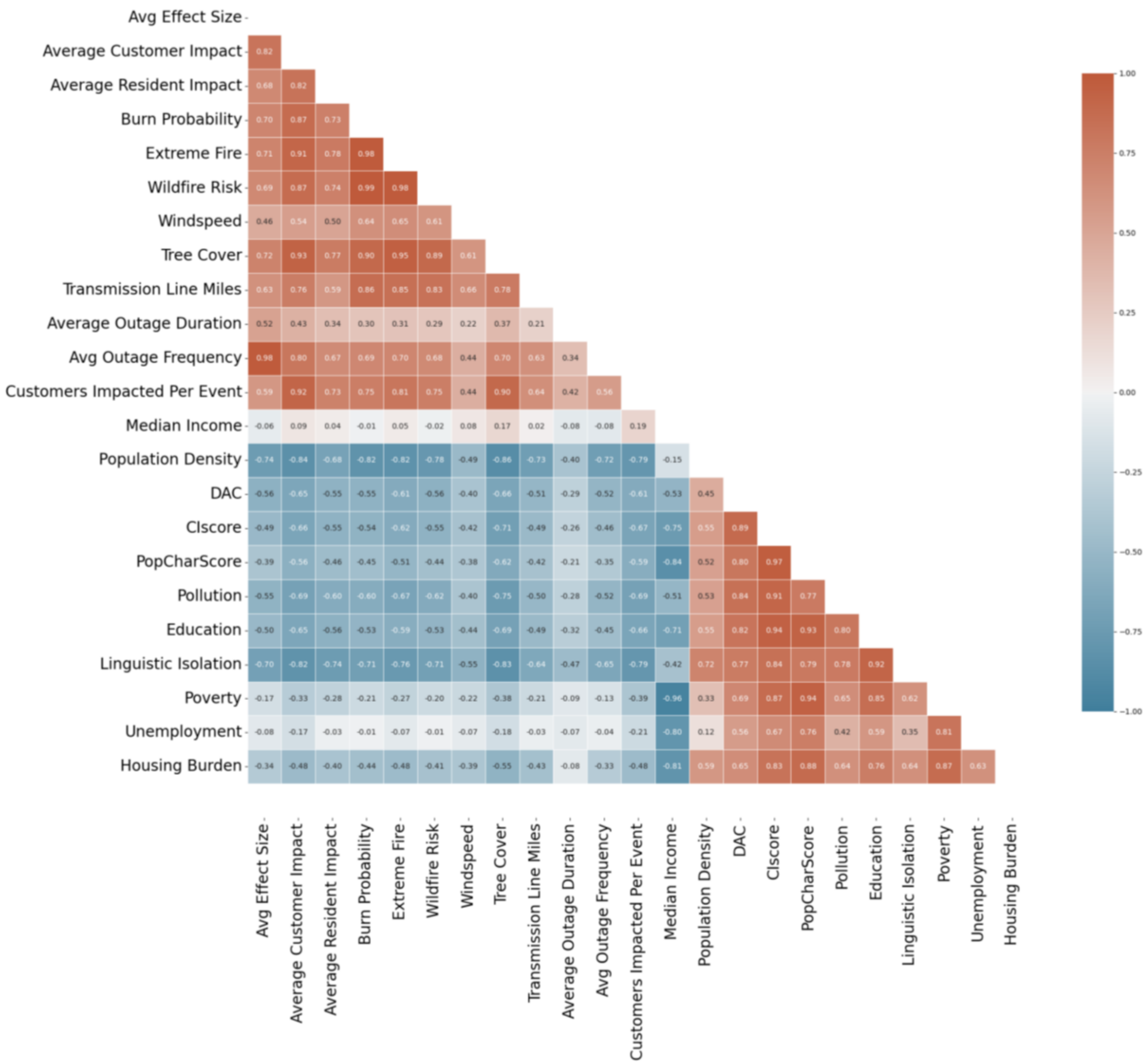

Figure 16. Correlation Matrix Between Wildfire and Demographic Factors with Outage Impacts

Microgrid grant eligibility

The following disadvantaged communities qualify for PG&E's Microgrid Incentive Program: Chico County (6007001300), Kern County (6029006202), Bakersfield County (6029006201), Butte County (6007003700), Stanislaus County (6099003400). The following high wildfire risk community qualifies for the incentive program: Trinity County (61050002000).

DISCUSSION

Through this analysis, I found that there are correlations between public safety power outage likelihood and various external factors, particularly weather. By assessing the direct causes of purposeful power outages, effective solutions can be better implemented. My findings suggest that certain Northern California inland communities may be under-represented in discussions surrounding outages, and may not be able to leverage grant money set aside to address power outage rates.

PSPS mapping

The high PSPS zones situated in California tend to be in northern, inland, rural communities (Figure 12, Figure 13, Figure 15). This suggests that wildfire risk, which includes a multitude of factors but is similarly concentrated in northern, inland, rural communities, does play an important role in PSPS (Figure 5, Figure 7). This means that to provide focused and effective change to provide reliable electricity, communities with high wildfire risk should be targeted for management techniques. Breaking down two factors that comprise wildfire risk (wind speed and vegetation) by census tract also shows some overlap. There are highly impacted outage communities along the Northern California coast which seem to overlap with the high max wind speeds found in those census tracts (Figure 8, Figure 10, Figure 11). High canopy cover zones along the California coast and in inland regions, also overlap with highly impacted outage communities (Figure 9).

Wildfire and demographic effects on PSPS

Communities with certain features such as higher burn probability, lower population density, and higher tree cover were found to have higher instances of PSPS (Figure 16). This suggests that due to the difficulty maintaining interconnection and lower customers connected in rural areas, utilities cannot prioritize and invest in appropriate infrastructure for the communities. It also stresses the importance of vegetation management as a critical factor in mitigating blackout risk. Another interesting feature was that there were no notable correlations between any of the analyzed factors and outage duration. This suggests that other factors, unrelated to wildfire or community demographics dictate how long it takes before the power is turned back on. This could also mean there are some internal processes at PG&E that determine the speed at which power is restored.

Grant eligibility

Microgrids could serve as an effective, long term solution to (Shah Danish et al. 2019; Perera et al. 2023). Microgrids provide electrical energy to communities even when disconnected from the larger electrical grid in times of extreme weather or overload. The Microgrid Incentive Program covers most highly affected communities and shows promise in improving electrical grid reliability across the state (PG&E 2023).

Limitations and future directions

The major limitation to this project was access to data. Some information that could have informed more precise analysis (such as number of customers in each region, exact location of distribution lines) was proprietary to PG&E and could not be shared with the public. As well, this data was not easily accessible or compiled on the utilities' side. Also, no clear public compilation of public safety power outages was readily available to the public despite individual records being public information. In the future, a reassessment of public safety power outages that have occurred in recent years and documenting their causes in outage reports would be helpful. Using this information, changes could be made to grant fund disbursement to provide money to communities that need it but do not qualify now. Another limitation was the spatial resolution of data. Generalizations were made across census blocks, and in the future finer grain analysis specifically around the power lines could improve our understanding of the issues at hand.

Broader implications

Access to reliable electrical power across the state no matter the situation makes it easier to manage the grid from a utility standpoint and improves the customers' experience. Understanding why outages take place is the first step to solving the problem. Many new grants to address this issue and provide funding for microgrids are available for communities (PG&E 2023). With this research and future studies, dependable electrical systems will be implemented across the state. While PSPS are a band aid solution to the risk of utility caused wildfire in California, the high cost of vegetation management has led to increased reliance on PSPS as a wildfire mitigation solution. Just in the past year, PG&E has decided to cut their vegetation management budget and concentrate on power line settings that will turn off the power whenever a risk is detected (Blunt 2023). If this is indeed the way forward, outages will likely be increasing across the state as there is a high correlation between vegetation and outages. So, a focus on implementing microgrids to at-risk communities is imperative. Microgrids will effectively reduce the risk of fire and vegetation management costs while also providing access to dependable power.

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